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TRANSPORTATION TEST OF DRY ICE REFRIGERATED TRUCK TRAILER - FLORIDA TO CHICAGO - MAY 1951

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Transportation Test of Dry Ice Refrigerated Truck Trailer - Florida to Chicago - May 1951 1/

A study was made of temperatures in trucks transporting frozen citrus concentrate from Florida to northern markets from April through October 1950. During this period 23 truck tests were conducted - two using dry ice (solid carbon dioxide) and the balance mechanical refrigeration. The results of these tests have been reported in Agricultural Information Bulletin 62. 2/ To keep the processors, carriers, and other interested parties informed on new developments, the test program has been continued in 1951. Two trucks were used in this test, one equipped with a new type of dry ice bunker and the other a mechanical refrigerating unit. These trucks were kept together on the trip from Plymouth, Fla., to Chicago, Ill., but due to deficiencies in the trailer equipped with the mechanical refrigerating unit and poor operation of the unit by the driver, an adequate comparison of their relative efficiencies was not obtained. Therefore, only the data relative to the performance of the dry ice refrigerated trailer are reported.

Semi-trailer and Refrigerating Equipment

The dry ice bunker was installed in a standard 30-foot tandem semi-trailer with 6 inches of fiberglass insulation in the ceiling and side walls and 4-1/2 inches of insulation in the floor. Outside sheathing was smooth aluminum and the inside sheathing plywood. The floor surface was constructed of lightweight metal with grooves 1 inch deep and 1 inch wide spaced 1/2 to 1-1/2 inches apart. The sidewalls and doors were stripped vertically with wood slats 1/2-inch thick and 3/4-inch wide spaced 5 inches apart. A small door, 40 by 15-1/2 inches, was installed in the curved surface of the right sidewall adjacent to the nose of the trailer to permit access to the bunker for icing.

Refrigeration was furnished by a cooler unit which consisted of a welded aluminum dry ice bunker bolted to the floor in the nose of the trailer. (See fig. 1.) The bunker had three shelves 1/4-inch thick, each capable of holding four 50-pound cakes of dry ice, making the total capacity 600 pounds. A sealed door on the right side of the unit gave access to the bunker shelves. The front surface of the bunker, protected by a double-walled steel housing, was finned to provide additional cooling surface. Two propeller-type electric fans maintained air circulation at the rate of 850 to 900 cubic feet per minute. These fans were operated by electric motors which were powered by the truck electrical

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1/ This is a report of a study conducted in part with funds appropriated under the Research and Marketing Act of 1946.

2/ Transportation of Frozen Citrus Concentrate by Railroad and Motortruck from Florida to Northern Markets, Agricultural Information Bulletin 62, June 1951.

system in transit and from any 110-volt source while standing. A thermostat attached to the right sidewall near the ceiling, approximately two-thirds of the distance from the unit to the rear doors, controlled one fan. On demand from the thermostat this fan started, drawing air from the floor level up over the finned surface of the bunker and discharging it near the ceiling. When the temperature in the cargo area reached the thermostat setting, the fan cut off. The other fan, which ran continuously, drew air from the floor level up a bypass in the back of the unit and discharged it at the ceiling level to maintain constant air circulation. Indicating lights were provided to show when either fan was operating. Carbon dioxide gas resulting from sublimation of the dry ice could be directed into the cargo area, as was done on these tests, or outside the vehicle by means of a valve located beside the bunker door.

Test Procedure

Commodity temperatures were obtained in nine locations and air temperatures in three locations by means of distant reading electrical resistance thermometers. The position of the thermometers in the load and their designations (fig. 1) were as follows:

	Position	Designation
Commodity -	Bottom bunker, centerline	BBCL
	Top bunker, centerline	TBCL
	Bottom bunker, right side	BBRS
	Bottom half, centerline	BHCL
	Top half, centerline	THCL
	Middle half, right side	MHRS
	Bottom half, right side	BHRS
	Top door, left side	TDLS
	Bottom door, centerline	BDCL
Air -	Bottom bunker, centerline	BBCL Air
	Top door, centerline	TDCL Air
	Bottom door, centerline	BDCL Air

Commodity temperatures were obtained by inserting the thermometer bulbs directly into the product after puncturing the cans. In the placement of the bulbs, cans next to the side of the case were used in positions along the side or end walls. The appropriate layer was used for top and bottom positions in cases with two layers of cans. The three resistance thermometer bulbs used to obtain air temperatures were placed in the designated positions so that they were not in contact with the load or structure of the vehicle. Loading temperatures were taken with hand thermometers as the commodity came out of cold storage, and destination temperatures were taken from the final resistance thermometer reading before the doors were opened for unloading. Temperature readings

from the resistance thermometers were recorded immediately after loading and at intervals of 8 hours or less during the transit period. During precooling periods and standing tests readings were recorded more frequently.

Three types of tests were conducted on the dry ice equipment: (1) Precooling test with empty trailer; (2) local road tests, in which the trailer was loaded with the product and traveled over the road in the vicinity of the processing plant during daylight hours to simulate transit conditions, then was parked at night; and (3) a transit test, in which the truck was loaded and accompanied by an observer from Plymouth, Fla., to Chicago, Ill.

The same general procedure was followed in icing the dry ice unit throughout this series of tests. A representative of the manufacturer of the unit was present while they were being conducted. He supervised the icing operations and made arrangements to have dry ice available at certain points for the tests in Florida and during the trip from Plymouth to Chicago. He also directed the amount of dry ice to be placed in the bunker and on the floor to supplement refrigeration furnished by the cooler unit and the time to ice and re-ice.

In re-icing, the trailer was usually drawn alongside a platform which was approximately the same height as the floor level of the trailer. The icing operation consisted of removing the wrapping paper from each cake, weighing the ice when scales were available or estimating the amount to be placed in the bunker and on the floor. When the unit was re-iced, the cakes remaining on the bunker shelves were removed from the bunker and placed on the floor on the left side of the unit, which operation required one man to enter the trailer through the access door. During the period of icing the blower fans were shut off and some warm outside air entered the trailer, causing sharp rises in the top air temperatures inside the trailer.

Precooling Test

A precooling test was conducted at Plymouth, Fla., on May 14 and 15, 1951, to observe the rate of pulldown, minimum temperatures obtainable under given conditions, range of temperature inside the trailer, rate of dry ice meltage, and to make preliminary observations on the general performance of the unit. Resistance thermometers for this test were placed so that eight top (3 inches from ceiling), and four bottom (1 to 2 inches above the floor), air temperatures could be obtained. (See table 1 for a complete record of temperature data and thermometer bulb locations and figure 2 for a graph of air temperatures.)

Initial icing started at 3:20 PM and was completed at 3:35 PM, May 14, at which time the outside temperature was 82°F. Four cakes of dry

ice were placed on each of the three bunker shelves; the 12 cakes weighed an estimated 580 to 600 pounds. An additional 3-1/2 cakes, approximately 150 pounds, were broken up and scattered over the floor to precool the trailer to a lower level and in less time than with the bunker charge alone. Total weight of the initial ice was approximately 740 pounds. After icing was completed the trailer was parked beside a warehouse and the power connection plugged into a 110-V electrical outlet.

Average top and bottom air temperatures inside the trailer reached 0°F. approximately 3-1/2 hours after initial icing. During this time the outside temperature ranged from 82° to 72°. By 8:00 PM air temperatures apparently reached an average minimum point at -2.1° (range -4.0° to 1.0°). A fractional rise was noted 1 hour later. Temperature readings were discontinued for the balance of the night.

By 10:55 AM the following day, May 15, air temperatures inside the trailer ranged from 17.0 to 20.5°F., averaging 18.5°. The outside air temperature at that time was 79°. An examination of the ice supply a short time later showed that approximately 20 percent (120 pounds) of the initial charge remained in the bunker. Ice meltage during the 20-hour period after initial icing totaled 620 pounds and averaged 31 pounds per hour. The rise in temperature can be attributed principally to the disappearnace of the ice scattered over the floor, diminution of the bunker supply and the increased solar heat load. The thermostat was set at 0°F., and the refrigerating fan operated continuously throughout the tests.

Re-icing started at 11:15 AM and was completed at 11:30 AM, at which time the outside temperature was 80°F. The 120 pounds of ice remaining in the bunker was removed from the trailer and the bunker recharged with an estimated 510 pounds. The cakes of ice remaining in the bunker from the initial charge were irregular in shape and weight.

Although no precooling data were obtained on a pull-down by the bunker alone, its apparent inability to maintain air temperatures in the empty trailer comparable to the level achieved with supplementary ice scattered over the floor was shown during the period following the re-icing. During the icing operation the access door of the trailer was open for approximately 15 minutes allowing the average air temperature to rise from 18.5°F. to 28.3°. Although the vehicle structure had been precooled for 20 hours prior to re-icing, subsequent readings showed a much slower rate of decrease in air temperatures compared to the period after initial icing, when the bunker ice was supplemented with ice on the floor.

A temperature reading made 4-1/2 hours after re-icing showed a ranged in air temperatures inside the trailer from 20.0° to 25.5° with an average of 22.5°. The bunker charge of approximately 510 pounds

reduced the average air temperature only 6.3 degrees in 4-1/2 hours.

Road Tests

Test conducted with grooved metal floor surface:

Since the bunker-unit apparently could not maintain air temperatures of 0°F. without supplementary dry ice placed in the body of the trailer, it was decided that a local road test under load be conducted in the vicinity of the plant before the transit test was undertaken. For this test the trailer was used as furnished by the carrier and previously described. Refrigeration furnished by the bunker was supplemented by varying amounts of dry ice placed on the floor adjacent to the bunker. During daylight hours the truck traveled in the vicinity of Plymouth with the bunker fans powered by the truck batteries. At night it was parked at the plant with the unit's fans powered from a 110-V electrical outlet. (See fig. 3 illustrating the load and figs. 4 and 5 for graphs of the temperature data.) The icing record and temperature data are shown in table 2.

The results of the test showed that the top and bottom centerline bunker positions were the points of minimum product temperature in the load and reflect their proximity to the refrigerant due to contact with the metal bunker surface. Average commodity temperatures were higher on the bottom of the load than on top principally because of insufficient air circulation around the load. Bottom commodity temperatures rose as much as 16.5 degrees in one position with an average rise of 4.0 degrees. Top commodity temperatures rose a maximum of 4.0 degrees and an average of 0.5 degrees. This indicated that more uniform and lower product temperatures could probably be obtained by achieving better air circulation around the load. Therefore a second local road test was conducted in an attempt to obtain improved temperature conditions.

Tests conducted with pallets simulating floor racks:

To improve air circulation around the load, six 2 by 4-inch stringers were placed lengthwise on the floor approximately 6 inches from each sidewall and 12 inches apart. Warehouse pallets 47-3/4 inches long, 36 inches wide, and 5-1/2 inches high were placed on top of the stringers in two rows of 6 pallets each. The space between the pallets and sidewalls and between the rows of pallets was fairly evenly distributed. (See fig. 6 which shows the pallet arrangement and figs. 7 and 8 for graphs of the temperatures.) A complete record of icings and temperature data is shown in table 3.

Greater air circulation around the load than provided by the grooved metal floor resulted in a somewhat smaller spread between the average top and bottom commodity temperatures. This spread, at the time of unloading, was reduced from 3.6 degrees with the grooved floor to 0.1 degree with the pallets. The range in temperature in all positions in the load was not narrowed, however. This was due to the point of minimum temperature in each test being in a package adjacent to the metal bunker, hence reflecting its proximity to the extremely low temperature refrigerant. The point of maximum temperature was also the same in each test, the bottom half right side position. This was caused by poor circulation of air down the sidewall and under the load at that point. The trailer was equipped with wooden floor racks in a further attempt to secure more uniform temperatures on the transit test. They consisted of six sections, 79-3/8 inches wide, 53 inches long, and with 1 by 4-inch cross slats spaced 3/4 inches apart and built up on eight 1-5/8 by 2-inch lengthwise stringers. Each section weighed approximately 105 pounds. The stripping on the rear doors was increased by the addition of 1-5/8 by 2-inch strips. (See fig. 9.)

Transit Test

The trailer with the dry ice bunker was initially iced from 12:05 to 12:25 PM, May 22. Twelve cakes of dry ice (556 pounds) were put in the bunker; eight cakes (321 pounds) were placed on the floor on the left side of the unit; and three cakes (125 pounds) were broken up and scattered over the floor racks, the total initial ice used amounting to 1,002 pounds. The outside temperature at the time of icing was 90°F. The trailer was precooled for 1 hour and 20 minutes. Air temperatures inside the trailer immediately before the doors were opened for loading ranged from 25.0° to 45.0°, which were much higher than recommended.

Loading of the 965 cases of frozen orange concentrate, 48 six-ounce can size, started at 1:45 PM and was completed at 2:30 PM. Product temperatures taken with hand thermometers during loading averaged 1.2°F. The truck left the plant at Plymouth at 2:35 PM. Normal operating stops were made en route, at which time temperature readings were obtained. (See table 4 and fig. 10 and 11 for temperatures en route.)

There was a layover at the truck terminal, Thomasville, Ga., from 10:45 PM, May 22, to 1:15 PM, May 23. The fans on the dry ice unit were powered by the tractor batteries during the transit period except at the layover, when 110-V current was used.

The dry ice unit was re-iced for the first time at Montgomery, Ala., from 8:25 to 8:45 PM on the 23rd, 32 hours after initial icing. Commodity temperatures obtained before the re-icing started ranged from 2.0° to 11.0°F., top positions averaged 7.3°, and bottom positions 5.4°; the

outside temperature was 64°. An estimated 20 to 25 pounds of ice remaining in the bunker was removed and put on the floor on the left side of the unit along with an additional 95 pounds. The bunker was recharged with 12 cakes which weighed 600 pounds.

Thirty cases of the product were removed from the trailer with the dry ice unit and transferred to the mechanically refrigerated trailer at a weighing station in Mississippi. This points out the necessity for planning weight distribution of the load prior to loading. The cases were transferred from the rear of the load through the side door to the other trailer between 3:15 and 3:30 AM, May 24, at which time the outside temperature was 54°F. The refrigerating unit was shut off during the time of transfer. Two thermometer bulbs, middle half right side and bottom half right side positions, were inadvertently pulled out of the test packages. No further temperature readings could be obtained from those positions.

The dry ice bunker was re-iced for the second time at Springfield, Ill., from 1:20 to 1:30 AM, May 25. The outside temperature at the time was 62°F. Ice remaining in the bunker, 75 pounds, was removed and put on the floor. Eight cakes of dry ice weighing a total of 410 pounds were placed in the bunker, 4 cakes on the bottom shelf and 2 cakes each on the middle and top shelves.

The truck arrived at the warehouse in Chicago at 9:45 AM, May 25. Unloading started at 10:15 AM and was completed at 11:45 AM. A temperature reading was made before the doors were opened for unloading, at which time the outside temperature was 76°F. Average temperature of the load, including two manual temperatures, was 3.3°, which was a rise of 2.1 degrees over loading temperature. Top commodity temperatures upon unloading ranged from -8.0° to 5.0°, averaging 0.7°. Bottom commodity temperatures ranged from -1.5° to 5.5° (excluding the bottom half right side position), averaging 2.5°. A product temperature of 10° was obtained in the test package at the bottom half right side with a hand thermometer during unloading. An estimated 250 pounds of dry ice remained in the bunker at the time of unloading. Total dry ice used during this 72-hour test period amounted to 2,107 pounds and total meltage 1,857 pounds. The average meltage for the trip was 25.8 pounds per hour. A summary of commodity temperatures for the transit test and the two local road tests is given in table 5.

SUMMARY

This test was conducted to determine the refrigerating efficiency of a new type dry ice system of truck refrigeration. The unit, installed in an insulated trailer, consisted of a dry ice bunker with finned surface and thermostatically controlled air circulation. The capacity of the bunker was 600 pounds of dry ice. In a precooling test of the empty trailer, an average air temperature of 0°F. was obtained by supplementing the full bunker charge with 150 pounds of dry ice broken up and spread over the floor of the trailer. After the dry ice on the floor sublimed, the unit was unable to maintain 0° with the bunker ice alone and the temperature rose to as high as 20°. The average air temperature inside the trailer, after the bunker was re-iced with a full charge of dry ice, was reduced only 6 degrees in 4-1/2 hours to an average of 22.5°.

Local road tests under load showed that the use of pallets, simulating wooden floor racks, resulted in a smaller spread between average top and bottom commodity temperatures than with the conventional grooved metal floor. This was due to improved air circulation which resulted from the greater air space under the load.

In the transit test to Chicago, Ill., the trailer was equipped with wooden floor racks. During this test the rise in average load temperature between loading and unloading was small (2.1 degrees). However, there was a greater fluctuation in product temperature en route as shown in fig. 10. The maximum average temperature was 6.2° just prior to the first re-icing at Montgomery. Temperatures were somewhat more uniform than on the previous local road tests, the spread between top and bottom positions averaging 3.1°F. However, a considerable amount of extra dry ice, in addition to that in the bunker, was placed on the floor beside the unit. As the supply of dry ice in the bunker diminished, commodity temperatures rose in the trailer.

The rates of dry ice meltage during these tests in pounds per hour were as follows: precooling test, 31 pounds; test with grooved metal floor surface, 21.9 pounds; test with pallets simulating floor racks, 24 pounds; and transit test 25.8 pounds.

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Table 1. -- Air temperatures during precooling test of trailer equipped with dry ice bunker, Plymouth, Fla., May 14 & 15, 1951

Place	May 1951	Time of day	OST	Temperatures from resistance thermometers located at -- TDCL	TDCL	THERMO-STAT	TQLS	TBCL	THCL	T3/4CL	T3/4CL	BHCL	BBCL	BQCL	BDCL	Max. temp. com.	Min. temp. com.	Avg. top temp. com.	Avg. bot. temp. com.
	Day		°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Plymouth, Florida	14	. .		Bunker initially iced 3:20 to 3:35 p.m. with 580-600 pounds dry ice, 150 pounds scattered over floor															
	14	3:45 p.m.	82	78.0	79.0	78.5	80.5	79.0	80.0	80.0	78.5	69.5	34.0	63.0	64.0	80.5	34.0	79.2	57.6
	14	4:15 p.m.	78	42.0	46.0	41.5	40.5	38.0	36.0	38.0	41.0	34.5	31.0	28.0	40.0	46.0	28.0	40.4	33.4
	14	4:45 p.m.	78	24.0	28.0	24.5	24.5	20.0	19.0	21.0	23.0	18.5	15.0	16.0	23.0	28.0	15.0	23.0	18.1
	14	5:30 p.m.	75	9.5	13.0	10.0	10.5	6.0	5.5	7.0	8.5	6.0	3.0	4.5	8.5	13.0	3.0	8.8	5.5
	14	6:00 p.m.	75	4.0	7.0	4.5	6.5	1.0	1.0	3.0	3.0	1.5	-0.5	1.0	3.0	7.0	-0.5	3.8	1.3
	14	7:00 p.m.	72	-1.0	2.0	-0.5	1.5	-2.5	-3.0	-1.0	-1.0	-2.5	-3.0	-3.0	-1.0	2.0	-3.0	-1.4	-2.4
	14	8:00 p.m.	71	-2.0	1.0	-1.5	0.5	-3.5	-4.0	-2.0	-2.0	-3.5	-3.0	-3.0	-2.5	1.0	-4.0	-1.7	-3.0
	14	9:00 p.m.	70	-2.0	0.5	-1.0	0.5	-3.5	-4.0	-2.0	-2.0	-3.0	-3.0	-3.0	-2.0	0.5	-4.0	-1.7	-2.8
	15	8:25 a.m.	75	8.0	10.0	9.5	10.5	8.0	7.0	9.0	8.0	7.5	8.0	8.0	8.0	10.5	7.5	8.8	7.9
	15	9:05 a.m.	75	12.0	13.0	13.5	14.5	11.0	10.5	12.5	12.0	11.5	11.0	11.0	11.5	14.5	10.5	12.4	11.3
	15	10:00 a.m.	78	14.5	16.0	16.5	18.0	14.0	13.5	15.5	14.5	14.5	14.5	15.0	15.0	18.0	13.5	15.3	14.8
	15	10:55 a.m.	79	19.0	20.0	19.5	20.5	17.0	17.0	19.0	18.0	17.5	18.0	18.0	18.0	20.5	17.0	18.8	17.9
	15			Re-iced 11:15 to 11:30 a.m. 120 pounds ice remaining in bunker removed, bunker recharged with 510 pounds															
	15	11:37 a.m.	82	30.0	31.0	30.5	32.5	28.0	28.0	30.0	29.0	26.5	25.0	28.0	27.0	32.5	25.0	29.9	26.6
	15	11:55 a.m.	82	27.0	28.0	27.5	29.5	25.0	24.0	26.0	26.0	25.5	25.0	25.0	26.0	29.5	24.0	26.6	25.4
	15	12:30 p.m.	83	24.0	26.0	25.5	27.5	23.0	22.0	25.0	24.0	24.5	24.0	24.0	24.0	27.5	22.0	24.6	24.1
	15	1:00 p.m.	83	24.0	25.0	25.5	27.5	22.0	21.0	23.0	24.0	24.5	23.0	23.0	23.0	27.5	21.0	24.0	23.4
	15	2:00 p.m.	83	23.0	24.0	23.5	25.5	21.0	20.0	22.0	22.0	22.5	22.0	22.0	22.0	25.5	20.0	22.6	22.1

Table 2. -- Local road test: Temperatures of commodity and air in dry ice refrigerated trailer equipped with conventional grooved metal floor, vicinity of Plymouth, Fla., May 15-17, 1951

Place	May 1951	Time of day	OST	Temperatures from resistance thermometers located at -- TDCL air	BBCL air	BDCL air	TBCL com.	TBCL com.	TDLS com.	BBRS com.	BDCL com.	BBCL com.	BBCL com.	BBRS com.	BBRS com.	Max. temp. com.	Min. temp. com.	Avg. top temp. com.	Avg. bot. temp. com.
	Day		°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Plymouth, Fla.	15	11:30 a.m.	82	Re-iced with estimated 510 lbs. after precooling test--all remaining dry ice from previous charge removed from trailer															
Davenport, Fla.	15	4:05 p.m.	80	24.0	22.0	24.0	23.0	24.0	24.0	24.5	25.0	25.5	24.5	24.0	21.0	25.5	21.0		
Davenport, Fla.	15		77	Loaded with 950 cases 48/6 oz. cans, 4:50 to 5:55 p.m.															
Davenport, Fla.	15	6:00 p.m.	77	71.0	58.0	55.0	5.0	14.0	15.0	4.5	4.0	0.5	-2.5	0.0	2.0	15.0	-2.5	11.3	0.8
Plymouth, Fla.	15	8:00 p.m.	73	11.0	7.0	13.0	5.0	7.0	8.0	5.5	5.0	1.5	4.5	5.0	4.0	8.0	1.5	6.7	4.0
Plymouth, Fla.	15	9:00 p.m.	70	8.0	4.0	9.0	4.0	7.0	7.0	5.5	5.0	1.5	3.5	5.0	5.0	7.0	1.5	6.0	4.0
Plymouth, Fla.	15	10:00 p.m.	70	6.0	3.0	8.0	4.0	6.0	7.0	5.5	5.0	1.5	3.5	5.0	5.0	7.0	1.5	5.7	4.0
Plymouth, Fla.	16	12:01 a.m.	70	5.0	2.0	6.0	3.0	6.0	6.0	5.5	5.0	2.5	3.5	5.0	6.0	6.0	2.5	5.0	4.4
Plymouth, Fla.	16	2:00 a.m.	69	5.0	1.0	6.0	2.0	5.0	6.0	5.5	5.0	2.5	3.5	4.0	7.0	7.0	2.0	4.3	4.4
Plymouth, Fla.	16	4:00 a.m.	63	5.0	1.0	6.0	1.0	5.0	5.0	5.5	5.0	2.5	3.5	4.0	7.0	7.0	1.0	3.7	4.4
Plymouth, Fla.	16	6:20 a.m.	65	5.0	2.0	6.0	1.0	4.0	5.0	5.5	4.0	2.5	2.5	3.0	7.5	7.5	1.0	3.3	3.9
				Re-iced from 7:00 to 7:10 a.m. - 80 to 100 pounds remaining in bunker removed and put on floor; bunker re-iced with estimated 480 pounds															
Plymouth, Fla.	16	7:10 a.m.	66	16.0	2.0	8.0	2.0	6.0	6.0	5.5	4.0	2.5	1.5	3.0	7.0	7.0	1.5	4.7	3.6
Apopka, Fla.	16	8:10 a.m.	77	-4.5	-9.0	-2.5	-2.5	1.5	2.5	5.5	3.0	2.5	-1.5	1.0	7.0	7.0	-2.5	0.5	2.4
Zelwood, Fla.	16	1:00 p.m.	88	0.0	-3.0	2.0	-2.0	1.0	4.0	7.5	3.0	3.5	-1.5	0.0	11.0	11.0	-2.0	1.0	3.2
Tavares, Fla.	16	2:00 p.m.	82	3.0	-1.0	4.0	-2.0	2.0	4.5	7.5	3.0	3.5	-1.5	1.0	12.0	12.0	-2.0	1.5	3.6
Plymouth, Fla.	16	4:00 p.m.	83	5.0	-1.0	5.0	-2.0	2.0	5.0	7.5	3.0	4.5	-0.5	2.0	12.0	12.0	-2.0	1.7	4.2
Plymouth, Fla.	16	5:30 p.m.	80	3.0	0.0	5.0	-2.0	2.0	5.0	7.5	3.0	4.5	-0.5	2.0	13.0	13.0	-2.0	1.7	4.4
Plymouth, Fla.	16	7:30 p.m.	74	3.5	-1.0	5.0	-1.0	2.0	5.0	8.5	3.5	4.5	-0.5	2.0	13.5	13.5	-1.0	2.0	4.6
Plymouth, Fla.	16	9:30 p.m.	70	2.5	-1.0	4.5	-2.0	2.0	4.5	7.5	3.0	4.5	-1.0	2.0	13.0	13.0	-2.0	1.5	4.3
Plymouth, Fla.	16	10:30 p.m.	70	3.0	-1.0	4.0	-2.0	2.0	4.5	7.5	3.0	4.5	-1.0	2.0	13.0	13.0	-2.0	1.5	4.3
Plymouth, Fla.	17	12:01 a.m.	70	3.0	-1.0	5.0	-2.0	2.0	4.5	8.5	3.0	5.0	-0.5	2.0	13.0	13.0	-2.0	1.5	4.5
Plymouth, Fla.	17	3:00 a.m.	69	6.0	2.0	7.0	-1.0	3.0	5.0	8.5	4.0	5.5	0.5	3.0	13.5	13.5	-1.0	2.3	5.3
Plymouth, Fla.	17	6:00 a.m.	65	7.0	3.0	7.5	0.0	3.0	6.0	8.5	4.0	5.5	1.5	4.0	13.5	13.5	0.0	3.0	5.7
				Re-iced 6:10 to 6:20 a.m.--82 lbs. remaining in bunker removed and put on floor, bunker re-iced with 538 pounds															
Plymouth, Fla.	17	6:20 a.m.	65	10.0	5.0	10.0	1.0	5.0	7.0	8.5	4.0	5.5	1.5	3.0	13.5	13.5	1.0	4.3	5.5
Plymouth, Fla.	17	7:40 a.m.		-2.5	-6.5	0.0	-2.0	1.0	4.0	8.5	4.0	5.0	-1.0	1.0	13.5	13.5	-2.0	1.0	4.5
Plymouth, Fla.	17	9:40 a.m.	77	-1.0	-4.0	1.0	-3.0	1.5	4.0	8.5	3.0	5.5	-0.5	0.5	14.5	14.5	-3.0	0.8	4.6
Plymouth, Fla.	17	1:25 p.m.	80	2.0	-2.0	4.0	-3.0	1.5	4.6	8.5	3.5	5.5	-1.0	0.5	14.5	14.5	-3.0	0.8	4.6
	17		80	Unloaded from 1:30 to 3:00 p.m.															
	17	3:00 p.m.		372 pounds dry ice remaining in bunker, 27 pounds on the floor															

Table 3. -- Local road test: Temperatures of commodity and air in dry ice refrigerated trailer with pallets simulating floor racks, vicinity of Plymouth, Fla., May 18-21, 1951

Place	May 1951	Time of day	OST	Temperatures from resistance thermometers located at -- TDCL air	BBCL air	BDCL air	TBCL com.	THCL com.	TDLS com.	MHRS com.	BDCL com.	BHCL com.	BBCL com.	BBRS com.	BHRS com.	Max. temp. com.	Min. temp. com.	Avg. top temp. com.	Avg. bot. temp. com.
	Day		°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Plymouth, Fla.	18			Initially iced 7:10 to 7:20 a.m. with 500 lbs. dry ice in bunker, 91 lbs. placed on floor left side of bunker, 136 lbs. broken and scattered over floor															
Plymouth, Fla.	18	7:28 a.m.	72	66.0	17.0	64.0	63.0	64.0	64.0	64.0	65.0	64.5	66.5	62.0	63.0				
Plymouth, Fla.	18	8:00 a.m.	76	25.5	15.0	24.0	17.0	21.0	21.0	22.5	23.0	18.5	19.5	18.0	18.0				
Plymouth, Fla.	18	9:00 a.m.	80	7.0	0.0	7.0	0.0	5.0	5.0	4.5	5.0	1.5	2.5	1.0	1.0				
Plymouth, Fla.	18	9:50 a.m.	81	2.0	-4.0	1.0	-4.0	0.0	0.0	-1.0	1.0	-2.5	-2.0	-3.5	-5.0				
Plymouth, Fla.	18	10:15 a.m.	81	12.0	-11.0	8.0	9.0	9.0	8.0	6.5	6.0	9.5	10.5	8.0	8.0				
				Doors open 11:10 a.m. to 12:01 p.m. for placement of pallets--loaded with 950 cases 48/6 oz. cans from 1:15 to 2:15 p.m.															
Plymouth, Fla.	18	2:25 p.m.	80	64.0	21.5	52.0	12.0	16.0	15.0	-2.0	5.0	-4.5	0.5	8.0	1.0	16.0	-4.5	14.3	2.0
Leesburg, Fla.	18	4:00 p.m.	78	21.5	23.0	19.0	7.0	7.0	10.5	-0.5	3.0	-2.5	7.5	8.0	4.5	10.5	-2.5	8.2	4.1
Plymouth, Fla.	18	6:05 p.m.	78	15.0	17.0	12.5	5.0	5.0	10.0	0.5	4.0	-1.5	14.5	8.0	6.5	14.5	-1.5	6.7	6.3
Plymouth, Fla.	18	9:00 p.m.	71	9.5	10.0	8.0	2.5	4.0	8.0	1.5	4.0	-1.5	12.0	7.5	7.0	12.0	-1.5	4.8	5.8
Plymouth, Fla.	19	6:00 a.m.	68	8.0	7.0	6.0	0.0	3.0	6.0	1.5	2.5	-1.5	11.0	5.0	6.5	11.0	-1.5	3.0	4.7
Plymouth, Fla.	19	6:30 a.m.		Re-iced: 550 lbs. dry ice in bunker, 130 lbs. placed on floor left side of bunker along with 87 lbs. remaining from previous icing															
Plymouth, Fla.	19	6:35 a.m.	68	22.0	6.0	12.0	2.0	6.0	9.0	3.5	3.5	-0.5	12.5	6.5	7.0	12.5	-0.5	5.7	5.8
Apopka, Fla.	19	7:20 a.m.	69	-1.0	4.0	-4.0	-3.0	-1.0	4.0	1.5	3.0	-1.5	9.5	4.0	7.0	9.5	-3.0	0.0	4.4
Mt. Dora, Fla.	19	8:00 a.m.	76	-2.0	4.0	-4.0	-3.0	-1.0	4.0	1.5	2.0	-1.5	8.5	4.0	7.0	8.5	-3.0	0.0	4.0
Leesburg, Fla.	19	9:00 a.m.	79	-2.0	3.0	-3.5	-4.5	-2.0	3.0	1.5	1.0	-1.5	5.5	2.0	7.0	7.0	-4.5	-1.2	2.8
Bedloview, Fla.	19	10:00 a.m.	84	0.0	5.0	0.0	-3.0	-1.0	4.0	2.5	2.0	-0.5	5.5	3.0	8.0	8.0	-3.0	0.0	3.6
Leesburg, Fla.	19	11:00 a.m.	84	1.0	5.0	-1.0	-3.5	-0.5	4.0	3.5	2.0	0.0	2.5	2.5	8.5	8.5	-3.5	0.0	3.1
Plymouth, Fla.	19	12:01 p.m.	82	2.0	6.0	1.0	-4.0	-0.5	4.0	3.5	2.0	0.0	1.5	2.0	8.5	8.5	-4.0	-0.2	2.8
Tavares, Fla.	19	2:00 p.m.	84	3.0	5.5	1.0	-2.0	-1.0	4.0	3.5	1.0	-0.5	0.5	1.0	8.0	8.0	-2.0	0.3	2.0
Leesburg, Fla.	19	4:00 p.m.	85	4.0	6.0	4.0	-3.5	0.5	5.0	4.5	2.0	0.0	1.5	2.0	9.0	9.0	-3.5	0.7	2.9
Plymouth, Fla.	19	5:30 p.m.	81	5.0	6.0	2.0	-3.0	1.0	5.0	4.5	2.0	0.5	1.5	2.0	9.0	9.0	-3.0	1.0	3.0
Plymouth, Fla.	19	9:00 p.m.	69	1.5	3.5	0.0	-6.0	-1.0	3.0	2.5	-1.0	-2.5	-1.5	0.0	8.0	8.0	-6.0	-1.3	0.6
Plymouth, Fla.	20	6:00 a.m.	63	3.0	3.5	1.5	-5.5	-1.0	2.5	2.5	-0.5	-2.5	-2.0	0.0	7.5	7.5	-5.5	-1.3	0.5
Plymouth, Fla.	20	6:30 a.m.		Re-iced: 500 lbs. dry ice added to bunker, 128 lbs of the 168 lbs of dry ice that remained in the bunker was taken out and placed on floor, left side of bunker															
Plymouth, Fla.	20	6:38 a.m.	63	18.0	2.0	8.0	-3.0	3.0	6.0	2.5	0.0	-2.5	-2.5	1.0	7.5	7.5	-3.0	2.0	0.7
Davenport, Fla.	20	9:00 a.m.	76	-2.0	3.0	-3.0	-7.0	-1.0	2.0	3.5	0.0	-1.5	-1.5	0.0	9.5	9.5	-7.0	-2.0	1.3
Plymouth, Fla.	20	11:20 a.m.	84	1.5	3.5	0.0	-7.0	-1.0	3.0	3.5	-1.0	-1.5	-1.5	0.0	9.0	9.0	-7.0	-1.7	1.0
Apopka, Fla.	20	2:15 p.m.	87	6.0	6.0	4.0	-6.5	1.0	5.5	4.5	0.5	-1.5	-1.0	1.0	10.0	10.0	-6.5	0.0	1.8
Plymouth, Fla.	20	6:15 p.m.	74	7.0	6.5	4.5	-7.0	1.0	5.5	4.5	0.5	-1.5	-2.5	2.0	10.0	10.0	-7.0	-0.2	2.0
Plymouth, Fla.	21	6:25 a.m.	70	6.0	5.0	4.0	-9.0	1.5	5.0	3.5	0.0	-3.0	-5.0	1.0	9.5	9.5	-9.0	-0.8	0.5
Plymouth, Fla.	21	10:20 a.m.	82	13.0	8.0	10.0	-5.0	5.0	8.0	5.5	3.0	-1.5	-3.5	4.0	12.0	12.0	-5.0	2.7	2.8
Plymouth, Fla.	21	10:21 a.m.	82	Unloaded 102 lbs. of dry ice remained in bunker.															

Table 4. -- Transit test: Temperatures of commodity and air in dry ice refrigerated trailer with floor racks en route from Plymouth, Fla., to Chicago, Ill., May 22-25, 1951

Place	May 1951	Time of day	OST	Temperatures from resistance thermometers located at -- TDCL air	BBCL air	BDCL air	TBCL com.	THCL com.	TDLS com.	MHRS com.	BDCL com.	BHCL com.	BBCL com.	BBRS com.	BHRS com.	Max. temp. com.	Min. temp. com.	Avg. temp top com.	Avg. temp bot. com.
	Day		°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Plymouth, Fla.	22	12:03 p.m.	90	92.0	84.0	91.0	86.0	90.0	90.0	90.0	90.0	89.0	90.0	90.0	90.0	90.0	86.0		
" "	22	12.07 p.m.	90	Iced 12:07-12:25 p.m. with 556 lbs. dry ice in bunker; 321 lbs. on floor left side of unit, and 125 lbs. broken and scattered over floor															
" "	22	12:40 p.m.	90	66.0	51.0	70.0	52.0	68.0	63.0	65.5	66.0	55.5	53.5	46.0	57.0	68.0	46.0		
" "	22	1:33 p.m.	90	41.0	33.0	45.0	29.0	42.0	38.5	39.5	41.0	32.0	31.0	25.0	34.0	42.0	25.0		
				Loaded from 1:45 p.m. to 2:25 p.m.--965 48/6 oz. cans															
" "	22	2:30 p.m.	91	88.0	-11.0	53.0	16.0	15.0	20.0	6.0	7.5	1.0	0.5	5.5	5.0	20.0	0.5	17.0	3.9
Belleview, Fla.	22	4:05 p.m.	89	5.5	-11.0	5.0	1.0	5.0	8.0	4.5	4.0	1.5	0.5	2.5	6.0	8.0	0.5	4.7	2.9
Thomasville, Ga.	22	10:50 p.m.	74	2.0	-6.0	5.5	-5.0	2.0	4.5	2.5	1.5	1.5	-0.5	2.0	6.0	6.0	-5.0	0.5	2.1
" "	23	5:05 a.m.	74	2.0	-1.5	5.0	-7.0	2.0	3.0	2.5	0.5	1.0	-1.5	1.0	5.0	5.0	-7.0	-0.7	1.2
" "	23	11:00 a.m.	84	9.0	3.5	11.0	-5.0	5.0	6.0	3.5	2.0	1.5	-1.5	3.0	6.0	6.0	-5.0	2.0	2.2
Dothan, Ala.	23	4:45 p.m.	88	13.5	9.0	15.5	-0.5	7.0	10.0	5.0	4.0	1.5	0.0	6.5	7.5	10.0	-0.5	5.5	3.9
Montgomery, Ala.	23	8:20 p.m.	64	14.5	11.0	16.0	2.0	9.0	11.0	6.5	6.0	2.5	2.0	8.0	8.5	11.0	2.0	7.3	5.4
" "	23			Bunker re-iced from 8:27 to 8:40 p.m. with 600 lbs. dry ice--95 lbs. placed on floor left side of unit (Approx. 25 lbs. remained in bunker)															
" "	23	8:45 p.m.	64	24.0	6.0	18.0	2.0	9.0	11.5	5.5	6.0	1.5	0.5	8.0	8.0	11.5	0.5	7.5	4.8
Columbus, Miss.	24	2:10 a.m.	54	-1.5	-0.5	0.0	-6.0	1.5	5.0	5.5	2.0	1.5	-1.0	2.0	7.0	7.0	-8.0	-0.5	2.3
	24			Side door opened from 3:15 to 3:30 a.m. to transfer 30 cases to another truck--thermometer bulbs MHRS and BHRS dislocated															
Tupelo, Miss.	24	6:15 a.m.	58	-2.0	0.0	0.0	-9.0	2.0	4.0	-	2.5	2.0	-1.5	2.0	-	4.0	-9.0	-1.0	1.3
Terrell, Ark.	24	11:30 a.m.	78	5.0	4.5	11.0	-7.0	4.5	6.0	-	2.0	2.5	-1.5	4.0	-	6.0	-7.0	1.2	1.8
Grant City, Mo.	24	4:35 p.m.	78	10.0	8.0	13.0	-3.0	7.0	8.0	-	4.0	3.0	-0.5	6.5	-	8.0	-3.0	4.0	3.3
Caryle, Ill.	24	9:40 p.m.	68	10.0	8.5	14.5	-3.0	9.0	8.5	-	5.0	2.5	-0.5	7.0	-	9.0	-3.0	4.8	3.5
Springfield, Ill.	25	1:15 a.m.	62	8.5	8.5	12.0	-2.0	9.0	8.0	-	5.5	2.5	0.0	8.0	-	9.0	-2.0	5.0	4.0
" "	25			Bunker re-iced from 1:20 to 1:30 a.m. as follows: The 75 lbs. that remained in bunker, placed on floor left side of unit--410 lbs. placed in bunker															
" "	25	2:10 a.m.	62	3.5	6.0	9.0	-4.0	5.0	7.0	-	4.0	2.5	-0.5	6.5	-	7.0	-4.0	2.7	3.1
Plainfield, Ill.	25	7:35 a.m.	74	2.0	3.0	6.0	-8.5	5.0	5.0	-	2.5	3.0	-1.5	5.5	-	5.5	-8.5	0.5	2.4
Chicago, Ill.	25	10:00 a.m.	76	5.0	4.0	8.0	-8.0	5.0	5.0	-	3.0	3.0	-1.5	5.5	-	5.5	-8.0	0.7	2.5
				Unloaded from 10:15 a.m. to 11:55 a.m.--estimated 250 lbs. dry ice remained in bunker															

Table 5. Product temperatures in dry ice refrigerated trailer taken during loading and at the time of unloading.

Position	Local road tests				Transit test 1/	
	Grooved floor		Pallets		Floor racks	
	Loading	Unloading	Loading	Unloading	Loading	Unloading
	°F	°F	°F	°F	°F	°F
BBCL	-1	-1.0	-6	-3.5	1	-1.5
BBRS	0	0.5	-6	4.0	1	5.5
BHCL	0	5.5	-6	-1.5	2	3.0
BHRS	-2	14.5	-6	12.0	1	10 2/
BDCL	0	3.5	-4	3.0	1	3.0
MHRS	0	8.5	-6	5.5	2	8 2/
TBCL	-1	-3.0	-6	-5.0	1	-8.0
THCL	0	1.5	-6	5.0	1	5.0
TDLS	0	4.5	-4	8.0	1	5.0
Average	-0.4	3.8	-5.6	3.1	1.2	3.3

1/ From Plymouth, Fla., to Chicago, Ill.

2/ Commodity temperature taken with hand thermometer during unloading.

REFRIGERATED TRUCK TRAILER EQUIPPED WITH A DRY ICE BUNKER

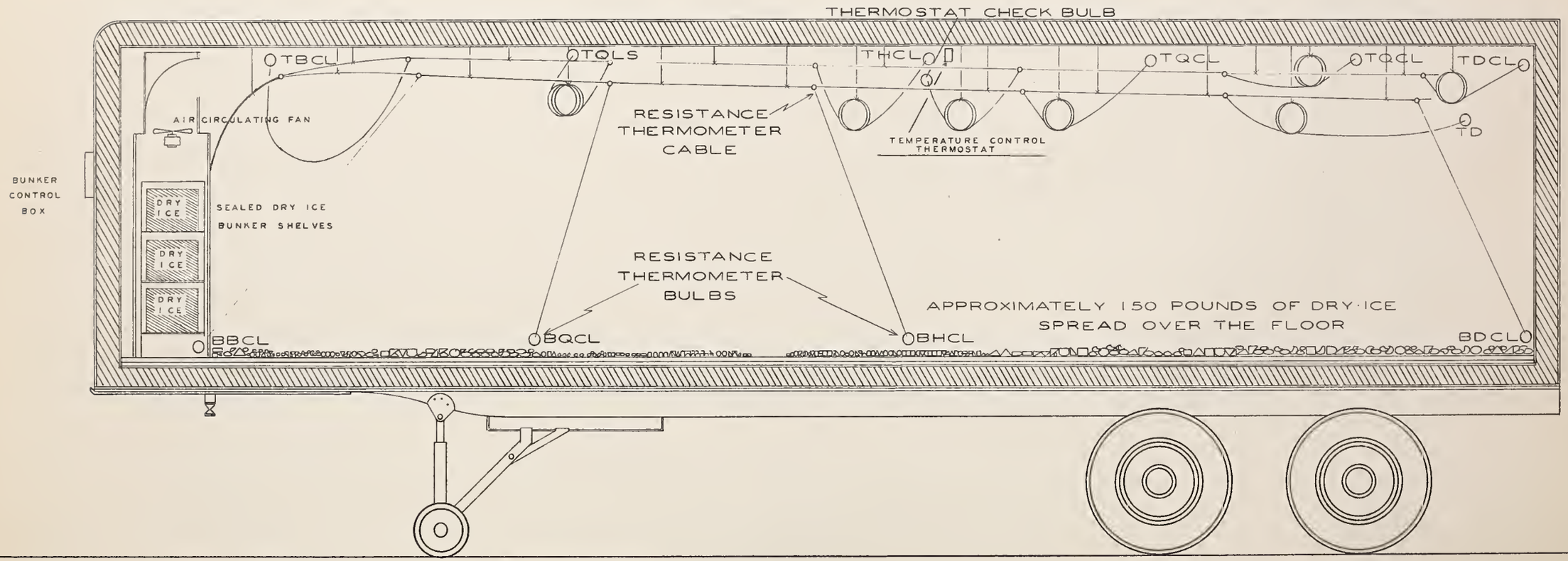

FIGURE 1.—LOCATION OF ELECTRICAL RESISTANCE THERMOMETERS DURING A PRECOOLING TEST OF THE EMPTY TRAILER USING 590 POUNDS OF DRY ICE IN THE BUNKER IN ADDITION TO APPROXIMATELY 150 POUNDS SPREAD OVER THE FLOOR. PLYMOUTH, FLA., MAY 14 AND 15, 1951.

AVERAGE AIR TEMPERATURES AT FLOOR AND CEILING IN THE EMPTY TRAILER TAKEN DURING THE PRECOOLING TEST

DRY ICE SYSTEM OF REFRIGERATION

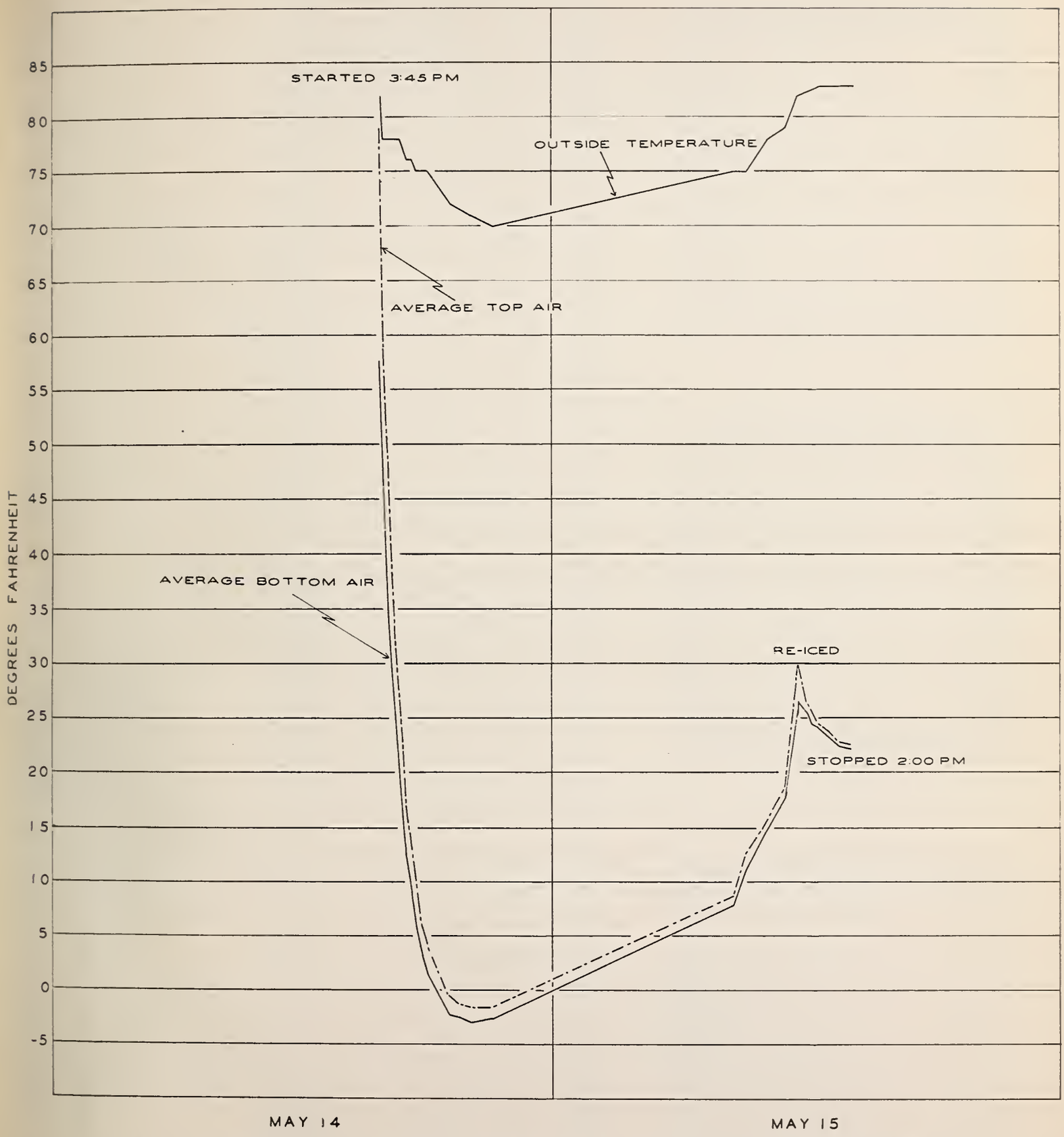

FIGURE NO. 2-PRECOOLING THE EMPTY TRAILER AT PLYMOUTH, FLA., MAY 14 AND 15, 1951.

REFRIGERATED TRUCK TRAILER EQUIPPED WITH A DRY ICE BUNKER

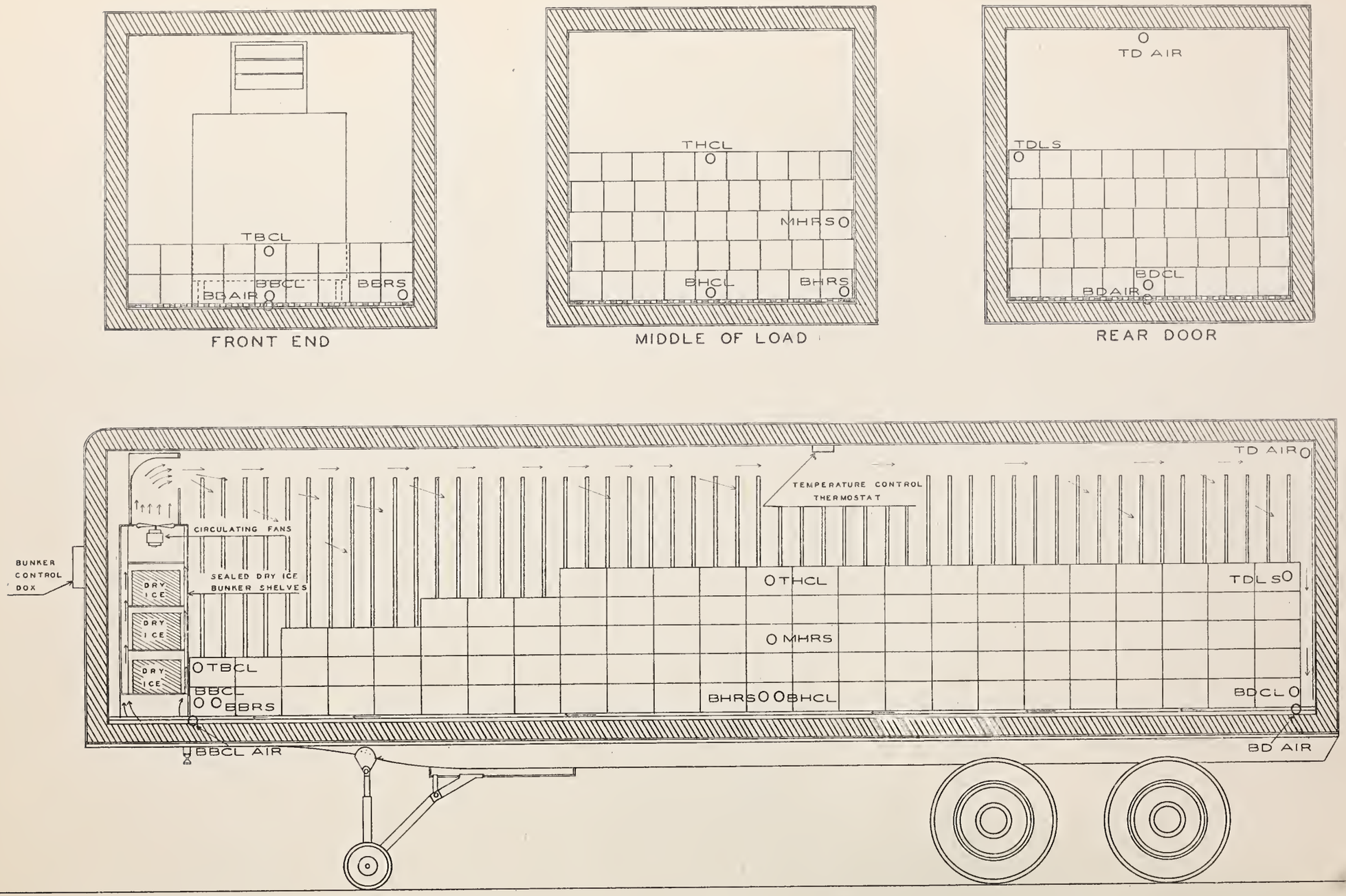

FIGURE 3—LOADING ARRANGEMENT AND LOCATION OF ELECTRICAL RESISTANCE THERMOMETERS THIS TEST WAS CONDUCTED IN THE VICINITY OF PLYMOUTH FLA., WITH THE CONVENTIONAL METAL GROOVED FLOOR MAY 15 TO 17, 1951.

AVERAGE AIR AND COMMODITY TEMPERATURES IN TRUCK TRAILER TEST
WITH THE CONVENTIONAL METAL GROOVED FLOOR
DRY ICE SYSTEM OF REFRIGERATION

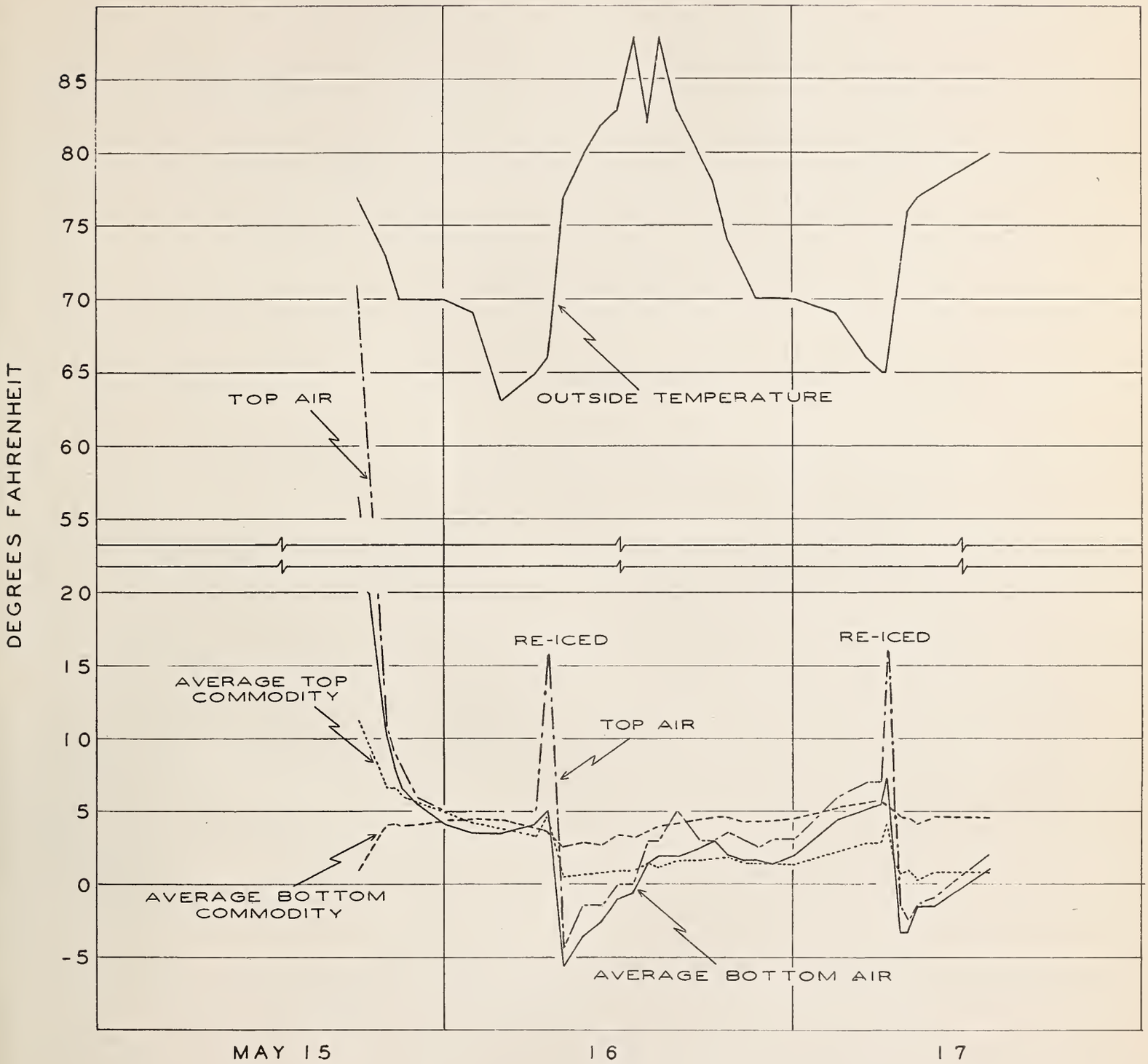

FIGURE .4—LOCAL ROAD TEST CONDUCTED IN THE VICINITY OF PLYMOUTH, FLA., MAY 15 TO 17, 1951.

COMMODITY TEMPERATURES

TEST WITH CONVENTIONAL METAL GROOVED FLOOR

DRY ICE SYSTEM OF REFRIGERATION

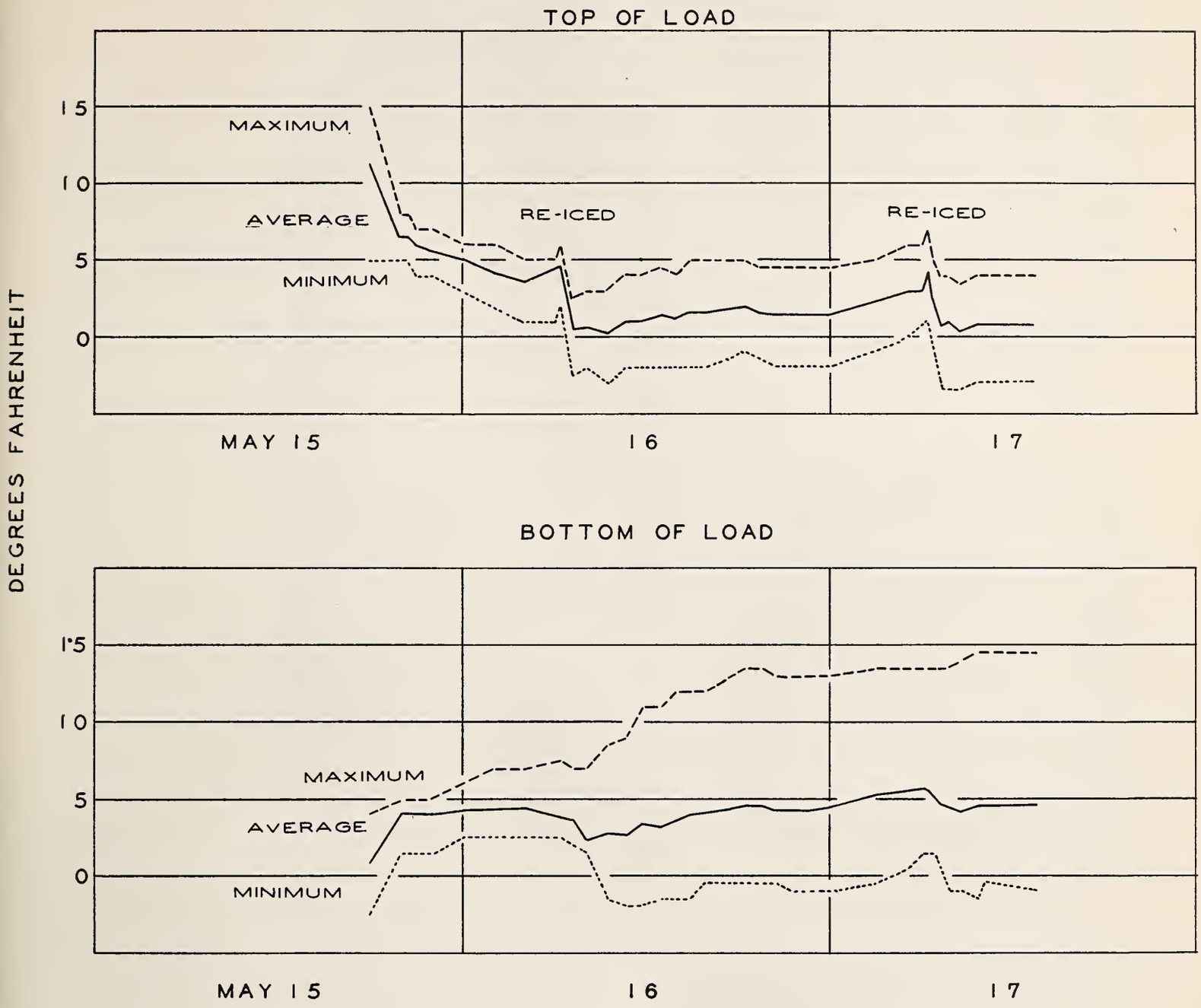

FIGURE 5-LOCAL ROAD TEST CONDUCTED IN THE VICINITY OF PLYMOUTH, FLA., MAY 15 TO 17, 1951.

REFRIGERATED TRUCK TRAILER EQUIPPED WITH A DRY ICE BUNKER

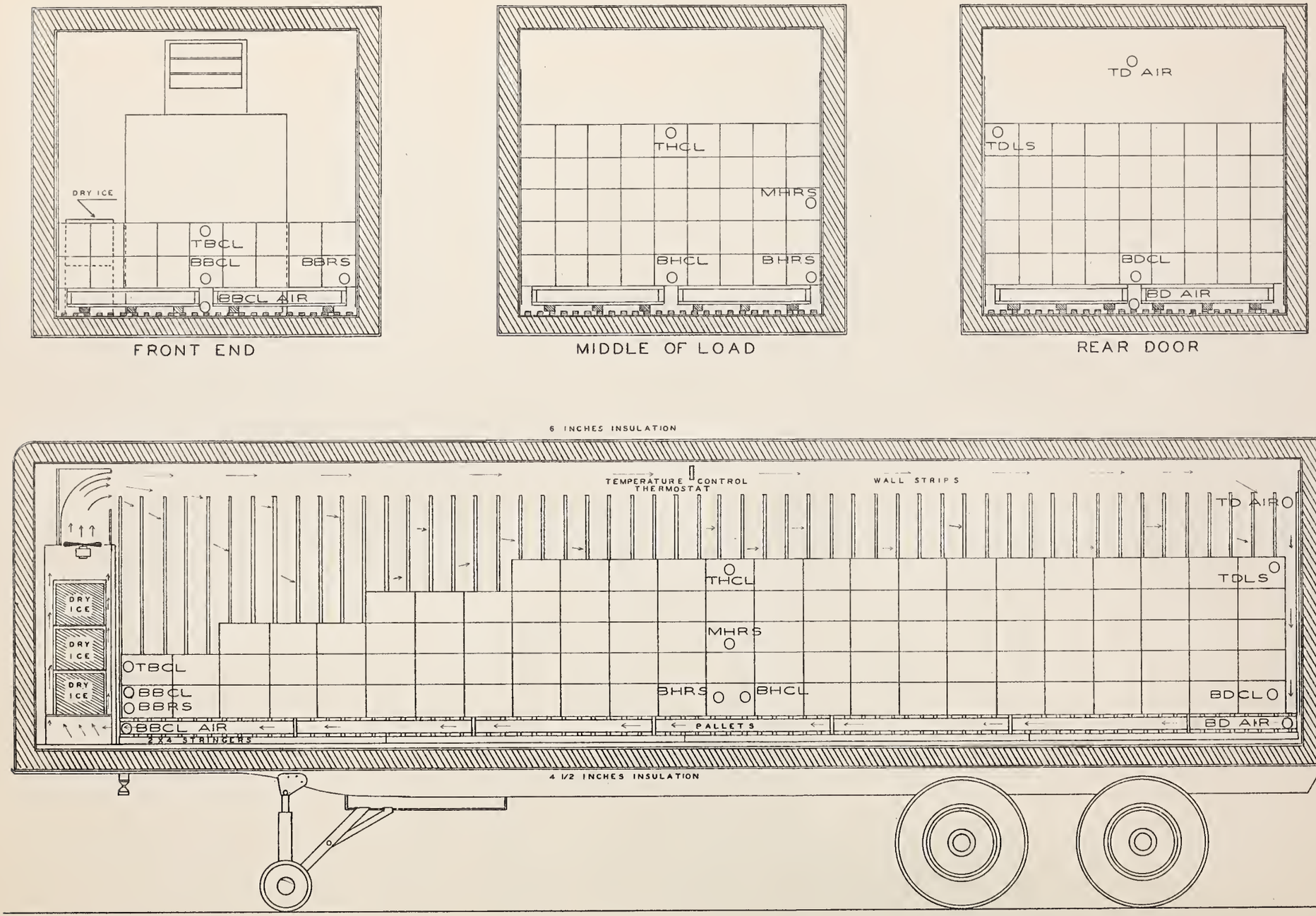

FIGURE 6– LOADING ARRANGEMENT AND LOCATION OF ELECTRICAL RESISTANCE THERMOMETERS IN A LOCAL ROAD TEST CONDUCTED IN THE VICINITY OF PLYMOUTH, FLA., MAY 18 TO 21, 1951. IN THIS TEST PALLETS WERE USED SIMULATING FLOOR RACKS TO INCREASE THE CIRCULATION OF AIR AROUND THE LOAD.

AVERAGE AIR AND COMMODITY TEMPERATURES IN TRUCK TRAILER TEST WITH WOODEN PALLETS TO SIMULATE FLOOR RACKS

DRY ICE SYSTEM OF REFRIGERATION

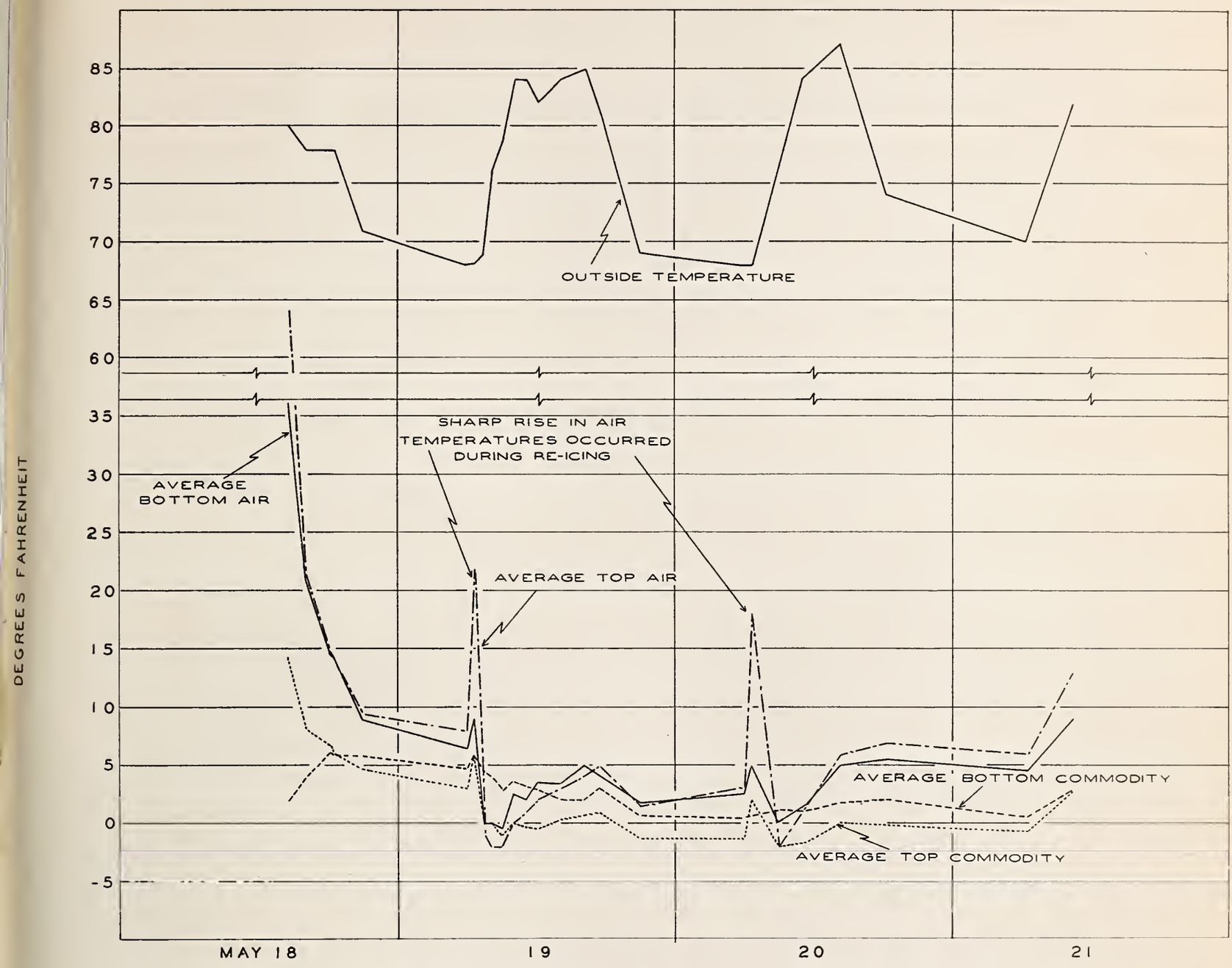

FIGURE 7-LOCAL ROAD TEST CONDUCTED IN THE VICINITY OF PLYMOUTH, FLA., MAY 18 TO 21, 1951

COMMODITY TEMPERATURES

TRUCK TEST WITH PALLETS SIMULATING FLOOR RACKS

DRY ICE SYSTEM OF REFRIGERATION

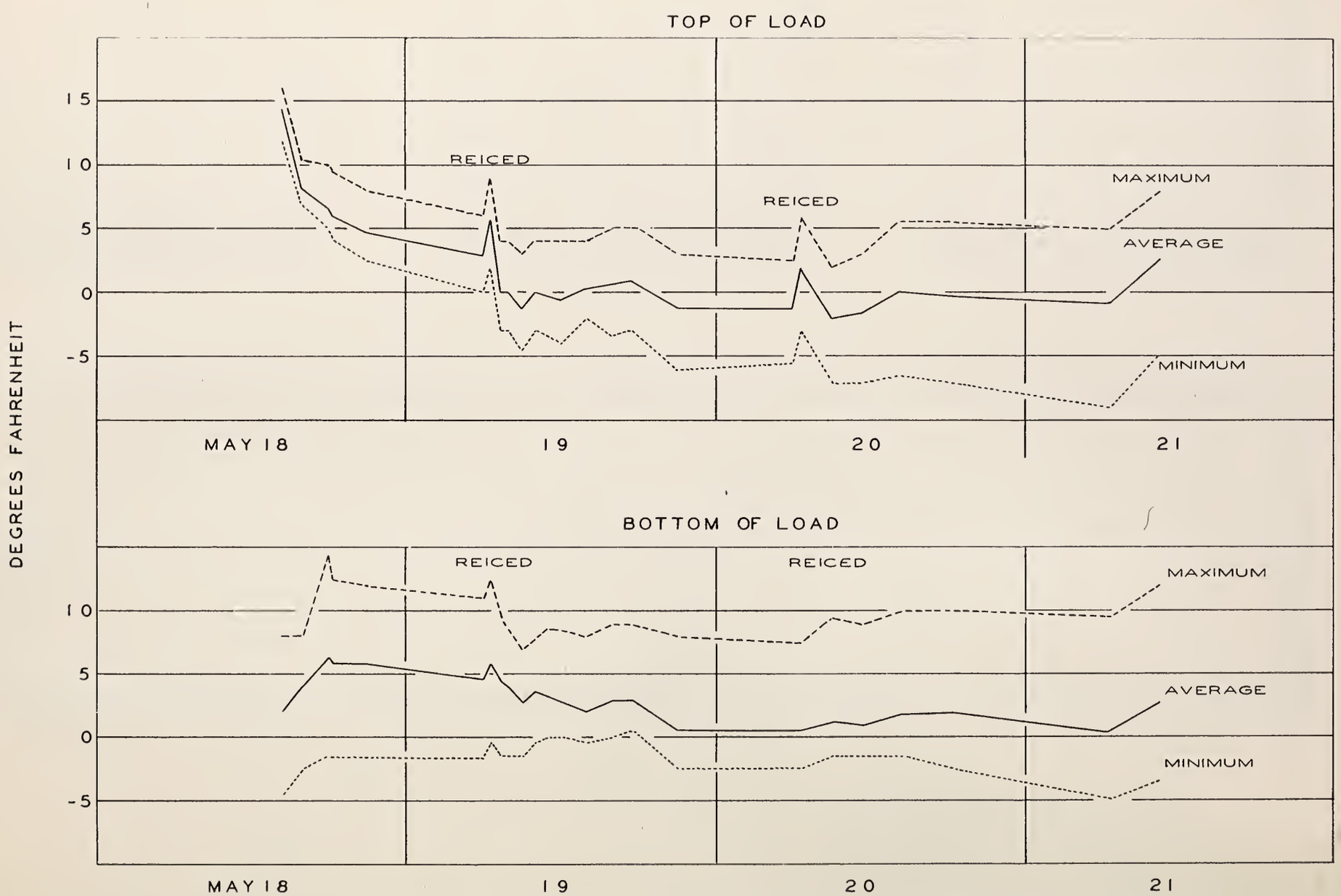

FIGURE 8- LOCAL ROAD TEST CONDUCTED IN THE VICINITY OF PLYMOUTH, FLA., MAY 18 TO 21, 1951.

REFRIGERATED TRUCK TRAILER EQUIPPED WITH A DRY ICE BUNKER

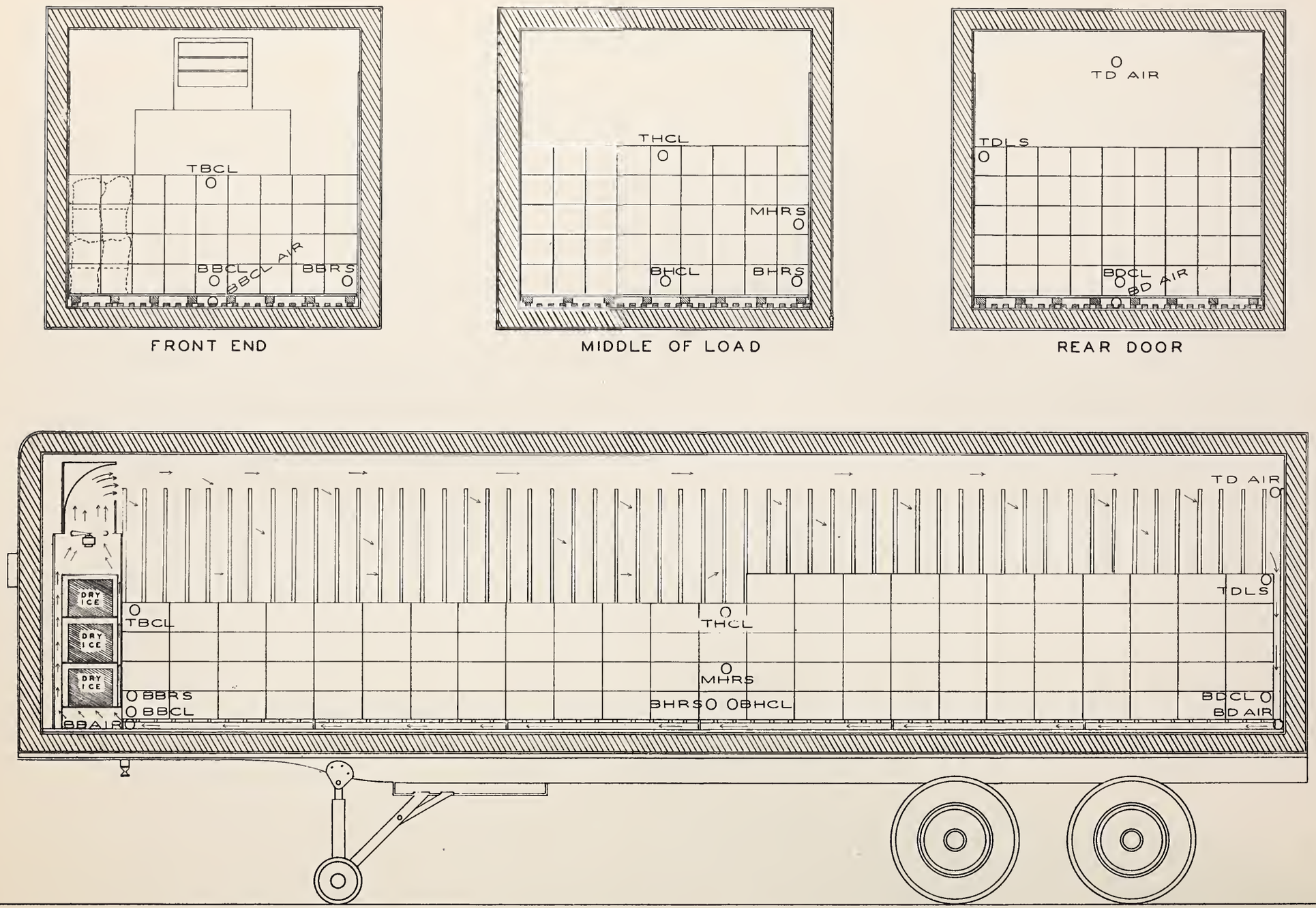

FIGURE 9—LOADING ARRANGEMENT AND LOCATION OF ELECTRICAL RESISTANCE THERMOMETERS IN A TEST CONDUCTED FROM PLYMOUTH, FLA., TO CHICAGO, ILL., MAY 22 TO 25, 1951. THIS TRAILER WAS EQUIPPED WITH TWO-INCH WOODEN FLOOR RACKS.

AVERAGE AIR AND COMMODITY TEMPERATURES IN TRUCK TRAILER TEST

WITH WOODEN FLOOR RACKS

DRY ICE SYSTEM OF REFRIGERATION

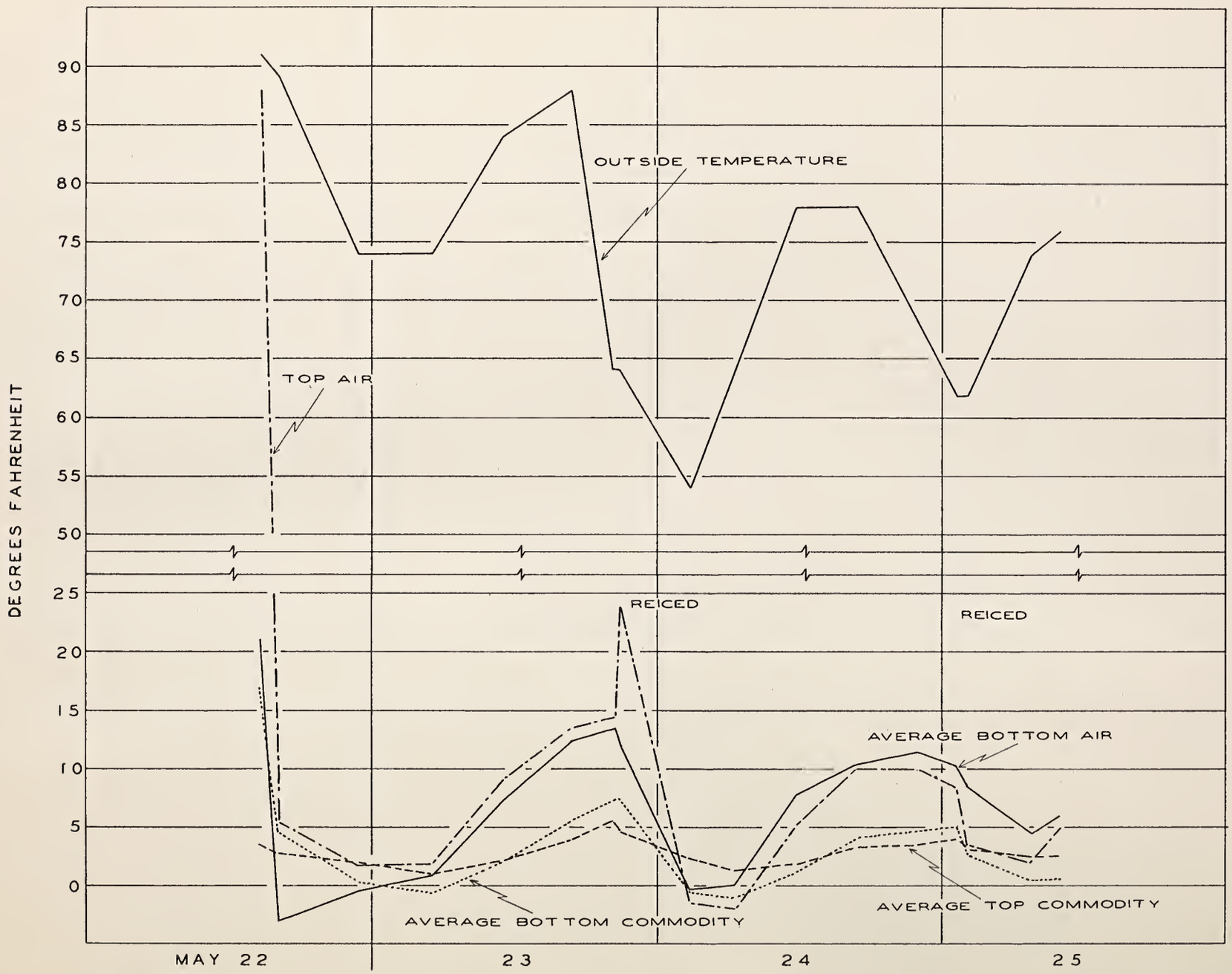

FIGURE 10-TEST CONDUCTED FROM PLYMOUTH, FLA., TO CHICAGO, ILL., MAY 22 TO 25, 1951.

COMMODITY TEMPERATURES

TRUCK TEST WITH WOODEN FLOOR RACKS

DRY ICE SYSTEM OF REFRIGERATION

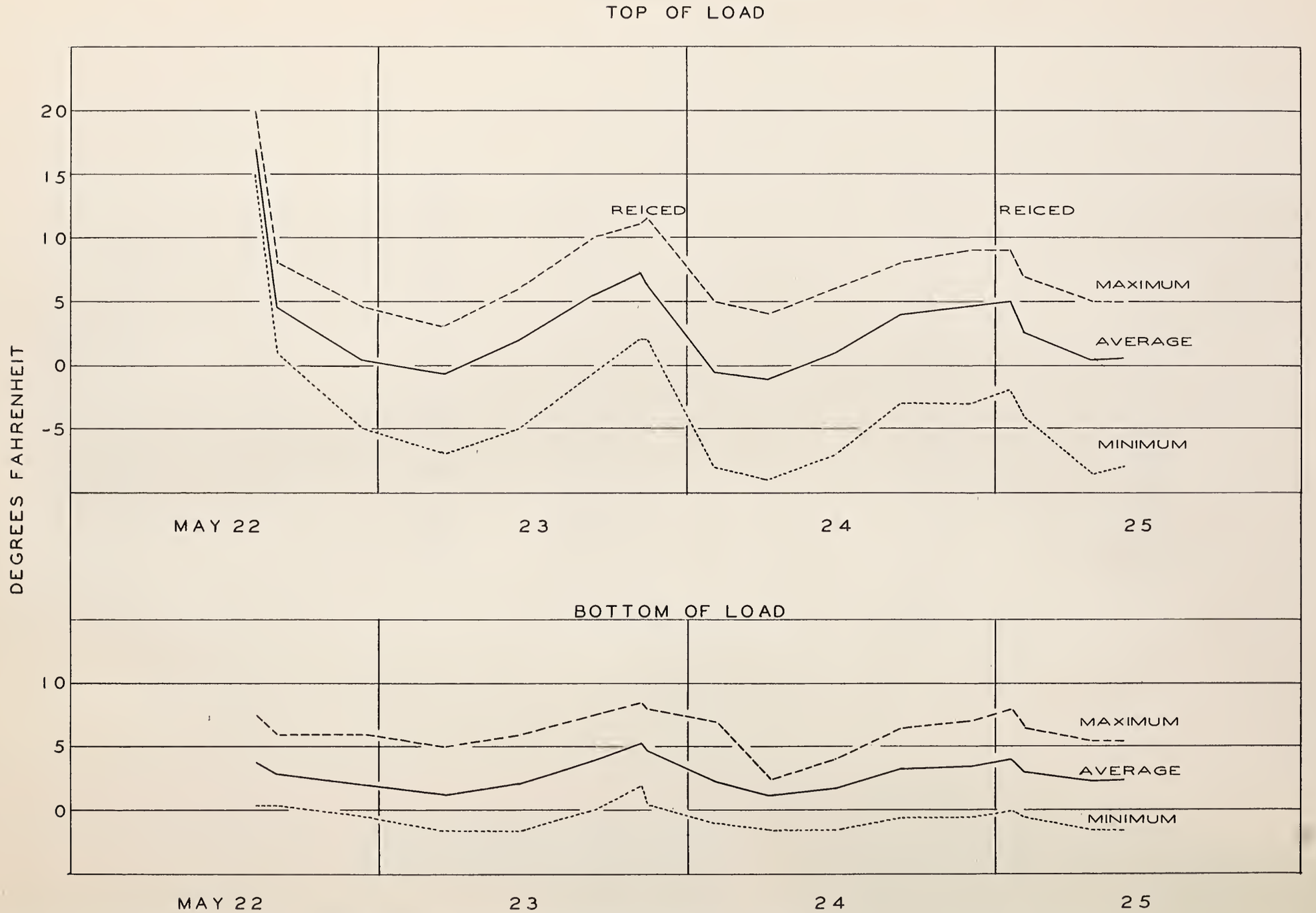

FIGURE 11-TEST CONDUCTED FROM PLYMOUTH, FLA., TO CHICAGO, ILL., MAY 22 TO 25, 1951.